IP MULTICAST WITH APPLICATIONS TO IPTV AND MOBILE DVB-H

Daniel Minoli

WILEY-INTERSCIENCE

A JOHN WILEY & SONS, INC., PUBLICATION

IP MULTICAST WITH APPLICATIONS TO IPTV AND MOBILE DVB-H

IP MULTICAST WITH APPLICATIONS TO IPTV AND MOBILE DVB-H

Daniel Minoli

WILEY-INTERSCIENCE

A JOHN WILEY & SONS, INC., PUBLICATION

Published by John Wiley & Sons, Inc.

Published simultaneously in Canada

Library of Congress Cataloging-in-Publication Data

Minoli, Daniel, 1952-
IP multicast with applications to IPTV and mobile DVB-H / Daniel Minoli.
p. cm.
Includes bibliographical references and index.
ISBN 978-0-470-25815-6 (cloth)
1. Webcasting. 2. Internet television. 3. Digital video. I. Title.
TK5105.887M578 2008
006.7–dc22

2007038116

Printed in the United States of America
10 9 8 7 6 5 4 3 2 1

For Anna and the kids.
And for my parents Gino and Angela

Also thanking
Mike Neen

CONTENTS

PREFACE

This book updates early-release published work undertaken by the author in the early-to-mid-1990s on the topic of video-for-telcos (“telco TV”), video-over-packet, video-over-DLS, and video-over-ATM contained in the book *Video Dialtone Technology: Digital Video over ADSL, HFC, FTTC, and ATM*, McGraw-Hill, 1995, and based on extensive hands-on work on broadband communications and digital video/digital imaging. At this juncture, the focus of this book (and for this industry) is completely on commercial-quality video over IP, IPTV.

Of late there has been renewed interest in IP multicast protocols and technologies because of the desire by traditional telephone companies to deliver entertainment-level video services over their network using next-generation infrastructures based on IP networking, by the cell phone companies for video streams to hand held telephone sets and personal digital assistants (PDAs), and by the traditional TV broadcast companies seeking to enter the same mobile video market. Critical factors in multicasting include bandwidth efficiency and delivery tree topology optimization.

IP multicast technology is stable and relatively easy to implement, particularly for architecturally simple (yet large) networks. A lot of the basic IP multicast mechanisms were developed in the mid-to-late 1980s, with other basic work undertaken in the 1980s. A number of recent functional enhancements have been added. From a commercial deployment perspective, IP multicast is now where IP was in the mid-1990s: poised to take off and experience widespread deployment. Examples of applications requiring one-to-many or many-to-many communications include but are not limited to digital entertainment video and audio distribution, multisite corporate videoconferencing, broad distribution financial data, stock quotes and news bulletins, database replication, software distribution, and content caching (for example, Web site caching).

The text literature on IP multicast is limited and somewhat dated, particularly in reference to IPTV applications. This compact text is intended for practitioners that seek a quick practical review of the topic with emphasis on the major and most-often used aspects of the technology. Given its focus on IPTV and DVB-H it can also be used by technology integrators and service providers that wish to enter this field.

Following an introductory discussion in Chapter 1, Chapter 2 covers multicast addressing for payload distribution. Chapter 3 focuses on multicast payload forwarding. Chapter 4 covers the important topic of dynamic host registration using the Internet Group Management Protocol. Chapter 5 looks at multicast routing in sparse-mode environments and the broadly used PIM-SM. Chapter 6 discusses CBT. Chapter 7 looks at multicast routing for dense-mode protocols and PIM-DM in particular. Chapter 8 examines DVMRP and MOSPF. The next chapter, Chapter 9, covers IP multicasting in IPv6 environments. Chapter 10 looks at Multicast Listener Discovery (MLD) snooping switches. Finally, Chapters 11 and 12 give examples in the IPTV and (mobile) DVB-H environments, respectively. Portions of the presentation are pivoted off and summarized from fundamental RFCs; other key sections are developed here for the first time, based on the author's multidecade experience in digital video. The reference RFCs and protocols are placed in the proper context of a commercial-grade infrastructure for the delivery of robust, entertainment-quality linear and nonlinear video programming.

Telephone carriers (telcos), cell phone companies, traditional TV broadcasters, cable TV companies, equipment manufacturers, content providers, content aggregators, satellite companies, venture capitalists, and colleges and technical schools can make use of this text. The text can be used for a college course on IP multicast and/or IPTV. There is now a global interest by all the telcos in Europe, Asia, and North America to enter the IPTV and DVB-H market in order to replace revenues that have eroded to cable TV companies and wireless providers. Nearly all the traditional telcos worldwide are looking into these technologies at this juncture. Telcos need to compete with cable companies and IPTV and DVB-H is the way to do it. In fact, even the cable TV companies themselves are looking into upgrading their ATM technology to IP. This book is a brand-new look at the IP multicast space.

ABOUT THE AUTHOR

Daniel Minoli has many years of technical hands-on and managerial experience (including budget and/or PL responsibility) in networking, telecom, video, enterprise architecture, and security for global best-in-class carriers and financial companies. He has worked at AIG, ARPA think tanks, Bell Telephone Laboratories, ITT, Prudential Securities, Bell Communications Research (now Telcordia), AT&T, Capital One Financial, and SES AMERICOM, where he is director of terrestrial systems engineering. Previously, he also played a founding role in the launching of two companies through the high-tech incubator Leading Edge Networks Inc., which he ran in the early 2000s; Global Wireless Services, a provider of secure broadband hotspot mobile Internet and hotspot VoIP services; and InfoPort Communications Group, an optical and Gigabit Ethernet metropolitan carrier supporting Data Center/SAN/channel extension and Grid Computing network access services.

For several years he has been Session-, Tutorial-, or overall Technical Program Chair for the IEEE ENTNET (Enterprise Networking) conference. ENTNET focuses on enterprise networking requirements for large financial firms and other corporate institutions.

At SES AMERICOM, Mr. Minoli has been responsible for engineering satellite-based IPTV and DVB-H systems. This included overall engineering design, deployment, and operation of SD/HD encoding, inner/outer AES encryption, Conditional Access Systems, video middleware, Set Top boxes, Headends, and related terrestrial connectivity. At Bellcore/Telcordia, he did extensive work on broadband; on video-on-demand for the RBOCs (then known as Video Dialtone); on multimedia over ISDN/ATM; and on distance learning (satellite) networks. At DVI he deployed (satellite-based) distance-learning system for William Patterson College. At Stevens Institute of Technology (Adjunct), he taught about a dozen graduate courses on digital video. At AT&T, he deployed large broadband networks also to support video applications, for example, video over ATM. At Capital One, he was involved with the deployment of corporate Video-on-demand over the IP-based intranet. As a consultant he handled the technology-assessment function of several high-tech companies seeking funding, developing multimedia, digital video, physical layer switching, VSATs, telemedicine, Java-based CTI, VoFR & VPNs, HDTV, optical chips, H.323 gateways, nanofabrication/(Quantum Cascade Lasers), wireless, and TMN mediation.

Mr. Minoli has also written columns for *ComputerWorld, NetworkWorld*, and *Network Computing* (1985–2006). He has taught at New York University (Information Technology Institute), Rutgers University, Stevens Institute of Technology, and

Monmouth University (1984–2006). Also, he was a Technology Analyst At-Large, for Gartner/DataPro (1985–2001); based on extensive hand-on work at financial firms and carriers, he tracked technologies and wrote around 50 CTO/CIO-level technical/architectural scans in the area of telephony and data systems, including topics on security, disaster recovery, IT outsourcing, network management, LANs, WANs (ATM and MPLS), wireless (LAN and public hotspot), VoIP, network design/economics, carrier networks (such as metro Ethernet and CWDM/DWDM), and e-commerce. Over the years, he has advised Venture Capitals for investments of $150M in a dozen high-tech companies. He has acted as Expert Witness in a (won) $11B lawsuit regarding a VoIP-based wireless Air-to-Ground communication system, and has been involved as a technical expert in a number of patent infringement proceedings.

1

INTRODUCTION TO IP MULTICAST

1.1 INTRODUCTION

Although "not much" new has occurred in the "science" of the Internet Protocol (IP) multicast space in the past few years, there is now keen interest in this technology because of the desire by traditional telephone companies to deliver entertainment-level video services over their networks using next-generation infrastructures based on IP networking and by the cell phone companies to deliver video streams to handheld telephone sets and Personal Digital Assistants (PDAs). A critical factor in multicasting is bandwidth efficiency in the transport network. IP multicast, defined originally in RFC 988 (Request for Comments) (1986) and then further refined in RFC 1054 (1988), RFC 1112 (1989), RFC 2236 (1977), RFC 3376 (2002), and RFC 4604 (2006), among others, is the basic mechanism for these now-emerging applications. The technology is stable and relatively well understood, particularly for architecturally simple (yet large) networks.

Even in spite of the opening statement above, enhancements to IP multicast have actually occurred in the recent past, including the issuing of Internet Group Management Protocol (IGMP), Version 3 (October 2002); the issuing of Multicast Listener Discovery

IP Multicast with Applications to IPTV and Mobile DVB-H by Daniel Minoli

(MLD), Version 2 for IP, Version 6 (IPv6) (June 2004); the issuing of Source-Specific Multicast (SSM) for IP (August 2006); and the publication of new considerations for IGMP and MLD snooping switches (May 2006). Work is also underway to develop new protocols and architectures to enable better deployment of IP over Moving Pictures Expert Group 2 (MPEG-2) transport and provide easier interworking with IP networks.

From a commercial deployment perspective, IP multicast is now where IP was in the mid-1990s: poised to take off and experience widespread deployment. Examples of applications requiring one-to-many or many-to-many communications include, but are not limited to, digital entertainment video and audio distribution, multisite corporate videoconferencing, broad-distribution financial data, grid computing, stock quotes and news bulletins distribution, database replication, software distribution, and content caching (e.g., Web site caching).

This book provides a concise guide to the IP multicast technology and its applications. It is an updated survey of the field with the underlying focus on IP-based Television (IPTV)[1] (also known in some quarters as telco TV) and Digital Video Broadcast—Handheld (DVB-H) applications.

IPTV deals with approaches, technologies, and protocols to deliver commercial-grade Standard-Definition (SD) and High-Definition (HD) entertainment-quality real-time linear and on-demand video content over IP-based networks, while meeting all prerequisite Quality of Service (QoS), Quality of Experience (QoE), Conditional Access (CA) (security), blackout management (for sporting events), Emergency Alert System (EAS), closed captions, parental controls, Nielsen rating collection, secondary audio channel, picture-in-picture, and guide data requirements of the content providers and/or regulatory entities. Typically, IPTV makes use of Moving Pictures Expert Group 4 (MPEG-4) encoding to deliver 200–300 SD channels and 20–40 HD channels; viewers need to be able to switch channels within 2 s or less; also, the need exists to support multi-set-top boxes/multiprogramming (say 2–4) within a single domicile. IPTV is not to be confused with simple delivery of video over an IP network (including video streaming), which has been possible for over two decades; IPTV supports all business, billing, provisioning, and content protection requirements that are associated with commercial video distribution. IP-based service needs to be comparable to that received over cable TV or direct broadcast satellite. In addition to TV sets, the content may also be delivered to a personal computer. MPEG-4, which operates at 2.5 Mbps for SD video and 8–11 Mbps for HD video, is critical to telco-based video delivery over a copper-based plant because of the bandwidth limitations of that plant, particularly when multiple simultaneous streams need to be delivered to a domicile; MPEG-2 would typically require a higher bit rate for the same perceived video quality. IP multicast is typically employed to support IPTV.[2]

[1] Some also use the expansion "IPTV (Internet TV)," e.g., CHA 200701. We retain the more general perspective of IPTV as TV (video, video on demand, etc.) distributed over any kind of IP-based network (including possibly the Internet).

[2] While some have advanced Peer-to-Peer (P2P) models for IPTV (e.g., see CHA 200701), nearly all the commercial deployment to date is based on the classical client–server model; this is the model discussed in this book.

Properly, DVB-H is a protocol. More broadly, DVB-H deals with approaches and technologies to deliver commercial-grade, medium-quality, real-time linear and on-demand video content to handheld, battery-powered devices such as mobile telephones and PDAs. IP multicast is also typically employed to support DVB-H.

1.2 WHY MULTICAST PROTOCOLS ARE WANTED/NEEDED

There are three types of communication between systems in an IP network:

- Unicast—here one system communicates directly to another system
- Broadcast—here one system communicates to all systems
- Multicast—here one system communicates to a select group of other systems

In traditional IP networks, a packet is typically sent by a source to a single destination (unicast); alternatively, the packet can be sent to all devices on the network (broadcast). There are business- and multimedia-entertainment applications that require a multicast transmission mechanism to enable bandwidth-efficient communication between groups of devices where information is transmitted to a single multicast address and received by any device that wishes to obtain such information. In traditional IP networks, it is not possible to generate a *single transmission* of data when this data is destined for a (large) group of remote devices. There are classes of applications that require distribution of information to a defined (but possibly dynamic) set of users. IP multicast, an extension to IP, is required to properly address these communication needs. As the term implies, IP multicast has been developed to support efficient communication between a source and multiple remote destinations.

Multicast applications include, among others, datacasting, distribution of real-time financial data, entertainment digital television over an IP network (commercial-grade IPTV), Internet radio, multipoint video conferencing, distance learning, streaming media applications, and corporate communications. Other applications include distributed interactive simulation, grid computing [MIN200401], and distributed video gaming (where most receivers are also senders). IP multicast protocols and underlying technologies enable efficient distribution of data, voice, and video streams to a large population of users, ranging from hundreds to thousands to millions of users. IP multicast technology enjoys intrinsic scalability, which is critical for these types of applications.

As an example in the IPTV arena, with the current trend toward the delivery of High-Definition TV (HDTV) signals, each requiring in the 12-Mbps range, and the consumers' desire for a large number of channels (200–300 being typical), there has to be an efficient mechanism of delivering a signal of 1–2 Gbps[3] in aggregate to a large number of remote

[3] Currently a typical digital TV package may consist of 200–250 SD signals each operating at 3 Mbps and 30–40 HD signals each operating at 12 Mbps; this equates to about 1 Gbps; as more HDTV signals are added, the bandwidth will reach in the range of 2 Gbps.

users. If a source had to deliver one Gbps of signal to, say, one million receivers by transmitting all of this bandwidth across the core network, it would require a petabit–per-second network fabric; this is not currently possible. On the contrary, if the source could send the 1 Gbps of traffic to (say) 50 remote distribution points (e.g., headends), each of which then makes use of a local distribution network to reach 20,000 subscribers, the core network needs to support 50 Gbps only, which is possible with proper design. For these kinds of reasons, IP multicast is seen as a bandwidth-conserving technology that optimizes traffic management by simultaneously delivering a stream of information to a large population of recipients, including corporate enterprise users and residential customers. See Figure 1.1 for a pictorial example.

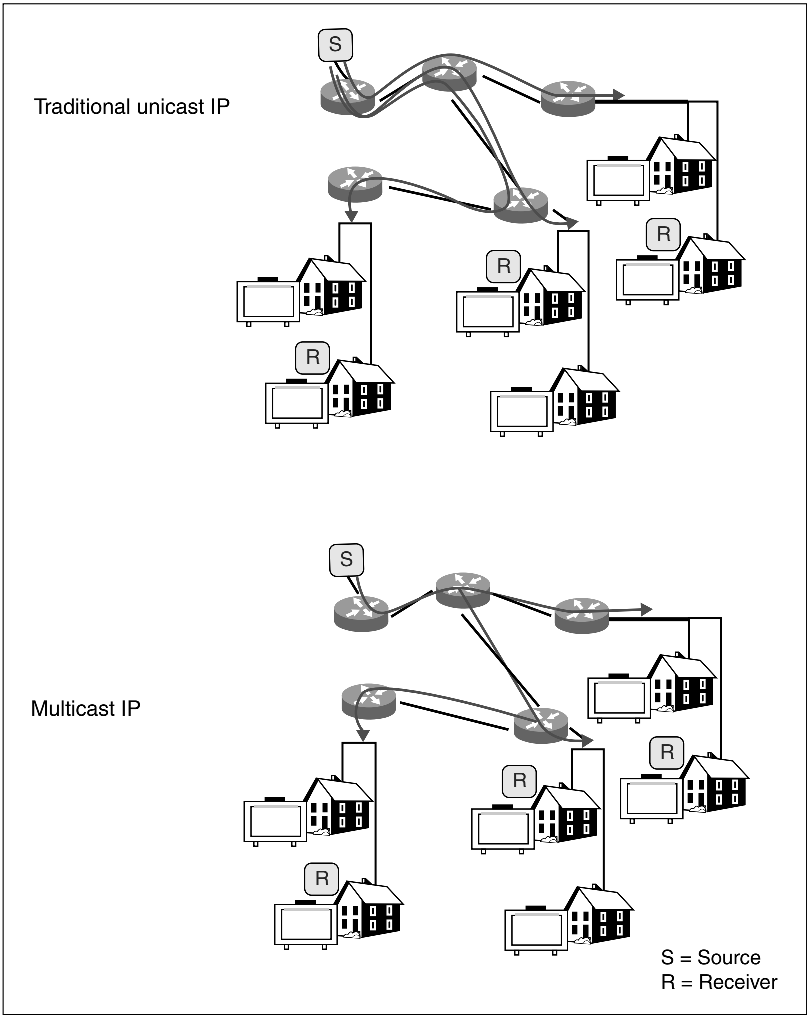

Figure 1.1. Bandwidth Advantage of IP Multicast

One important design principle of IP multicast is to allow receiver-initiated attachment (joins) to information streams, thus supporting a distributed informatics model. A second important principle is the ability to support optimal pruning such that the distribution of the content is streamlined by pushing replication as close to the receiver as possible. These principles enable bandwidth-efficient use of underlying network infrastructure.

The issue of security in multicast environments is addressed via conditional access systems that provide per-program[4] encryption (typically, but not always, symmetric encryption) (also known as inner encryption) or aggregate IP-level encryption (again typically, but not always, symmetric encryption) (also known as outer encryption).

1.3 BASIC MULTICAST PROTOCOLS AND CONCEPTS

Multicast communication is based on the construct of a group of receivers (hosts) that have an interest in receiving a particular stream of information, be it voice, video, or data. There are no physical or geographical constraints, or boundaries, to belong to a group, as long as the hosts have (broadband) network connectivity. The connectivity of the receivers can be heterogeneous in nature, in terms of bandwidth and connecting infrastructure (e.g., receivers connected over the Internet), or homogenous (e.g., IPTV or DVB-H users). Hosts that are desirous of receiving data intended for a particular group join the group using a group management protocol: hosts/receivers must become explicit members of the group to receive the data stream, but such membership may be ephemeral and/or dynamic. Groups of IP hosts that have joined the group and wish to receive traffic sent to this specific group are identified by multicast addresses, as discussed below.

Multicast transmission mechanisms for multipoint distribution are available at both the data link layer (layer 2) and the network layer (layer 3). Of late, the focus has been on layer 3 IP-level systems. There are local-area network (LAN)–level approaches to multicast, but typical contemporary business applications (e.g., IPTV) require a reach of a campus or, even more likely, a wide-area environment.

Deering's work in the late 1980s defined the IP multicast service model, and he invented algorithms that allow hosts to arbitrarily join and leave a multicast group [RFC1054, RFC1112, RFC2201].

Multicast transmission at layer 3 involves several mechanisms, as we discuss next. Below, we briefly outline key concepts; all of the material introduced below will be discussed in detail in appropriate chapters in the text.

Addressing for Payload—To communicate with a group of receivers (hosts), one needs a layer 3 address; also, there must be a mechanism of mapping the layer 3 address onto layer 2 multicast addresses of the underlying LAN. Ethernet multicast

[4] A program in this context equates to a video channel, more specifically to an MPEG-2/4 transport stream with a given Program ID (PID) (this topic is revisited in Chapters 2 and 11).

addresses have a hex "01" in the first byte of the six-octet destination address. The Internet Assigned Numbers Authority (IANA) manages the assignment of IP addresses at layer 3, and it has assigned the (original) Class D address space to be used for IP multicast. A Class D address consists of 1110 as the higher order bits in the first octet, followed by a 28-bit group address. A 1110-0000 address in the first byte starts at 224 in the dotted decimal notation; a typical address might be 224.10.10.1, and so on. All IP multicast group addresses belong to the range 224.0.0.0–239.255.255.255. In addition, all IPv6 hosts are required to support multicasting. The mapping of IP multicast addresses to Ethernet addresses takes the lower 23 bits of the Class D address and maps them into a block of Ethernet addresses that have been allocated for multicast.

Dynamic Host Registration—There must be a mechanism that informs the network that a host (receiver) is a member of a particular group (otherwise, the network would have to flood rather than multicast the transmissions for each group). For IP networks, the IGMP serves this purpose.

Multicast Payload Forwarding—Typical IP multicast applications make use of User Datagram Protocol (UDP) at the transport layer and IP at the network layer. UDP is the "best effort delivery" protocol with no guarantee of delivery; it also lacks the congestion management mechanism [such as those utilized in Transmission Control Protocol (TCP)]. Real-time applications such as commercial live video distribution do not (and cannot) make use of a retransmission mechanism (such as the one utilized in TCP). In some cases, portions of the network may be simplex (such as a satellite link), practically precluding end-to-end retransmission. Hence, the risk exists for audio and video broadcasts to suffer content degradation due to packet loss. To minimize lost packets, one must provision adequate bandwidth and/or keep the distribution networks simple and with as few hops as possible. IP QoS (*diffserv*), the Real-Time Transport Protocol (RTP), and 802.1p at layer 2 are often utilized to manage QoS. [To minimize in-packet bit corruption, Forward Error Correction (FEC) mechanisms may be used—a state-of-the-art mechanism can improve Bit Error Rates (BERs) by an impressive four or five orders of magnitude.]

Multicast Routing—A multicast network requires a mechanism to build distribution trees that define a unique forwarding path between the subnet of the content source and each subnet containing members of the multicast group, specifically, receivers. A principle utilized in the construction of distribution trees is to guarantee that at most one copy of each packet is forwarded on each branch of the tree. This is implemented by ascertaining that there is sufficient real-time topological information at the multicast router of the source host for constructing a spanning tree rooted at said multicast router (or other appropriate router) and providing connectivity to the local multicast routers of each receiving host. A multicast router forwards multicast packets to two types of devices: downstream-dependent routers and receivers (hosts) that are members of a particular multicast group. See Table 1.1 for a list of some key multicast-related protocols.

Multicast routing protocols belong to one of two categories: Dense-Mode (DM) protocols and Sparse-Mode (SM) protocols.

TABLE 1.1. Multicast Protocols At a Glance

Protocol	Function
IGMP	Client [receiver, Set-Top Box (STB), PC] to router signaling
Protocol Independent Multicast (PIM) Distance Vector Multicast Routing Protocol (DVMRP) Core-Based Tree (CBT) Multicast Open Shortcut Path First (MOSPF)	Router to router topology (multicast route) management
Multiprotocol BGP (MBGP) Multicast Source Discovery Protocol (MSDP)	Large-scale router to router
GLOP Multicast Address Dynamic Client Allocation Protocol (MADCAP) Multicast Address Set Claim Protocol (MASC)	Multicast address allocation
Cisco Group Management Protocol (CGMP) GARP Multicast Registration Protocol (GMRP) IGMP snooping Router-Port Group Management Protocol (RGMP)	Router to switch (Cisco specific)

- DM protocols are designed on the assumption that the majority of routers in the network will need to distribute multicast traffic for each multicast group. DM protocols build distribution trees by initially flooding the entire network and then pruning out the (presumably small number of) paths without active receivers. The DM protocols are used in LAN environments, where bandwidth considerations are less important but can also be used in wide-area networks (WANs) in special cases (e.g., where the backbone is a one-hop broadcast medium such as a satellite beam with wide geographic illumination, e.g., in some IPTV applications).
- SM protocols are designed on the assumption that only few routers in the network will need to distribute multicast traffic for each multicast group. SM protocols start out with an empty distribution tree and add drop-off branches only upon explicit requests from receivers to join the distribution. SM protocols are generally used in WAN environments, where bandwidth considerations are important.

For IP multicast, there are several multicast routing protocols that can be employed to acquire real-time topological and membership information for active groups. Routing protocols that may be utilized include the PIM, the DVMRP, the MOSPF, and CBTs. Multicast routing protocols build distribution trees by examining the routing forwarding table that contains unicast reachability information. PIM and CBT use the unicast forwarding table of the router. Other protocols use their specific unicast reachability routing tables; for example, DVMRP uses its distance vector routing protocol to determine how to create source-based distribution trees, whereas MOSPF utilizes its link-state table to create source-based distribution trees. MOSPF, DVMRP, and PIM DM are DM routing protocols, whereas CBT and PIM SM are SM routing protocols. PIM is currently the most widely used protocol.

Specifically, PIM Version 2 (PIMv2) is a protocol that provides intradomain multicast forwarding for all underlying unicast routing protocols [e.g., Open Shortest Path First (OSPF) or BGP], independent from the intrinsic unicast protocol. Two modes exist: PIM SM and PIM DM.[5]

PIM DM (defined in RFC 3973, January 2005) is a multicast routing protocol that uses the underlying unicast routing information base to flood multicast datagrams to all multicast routers. Prune messages are used to prevent future messages from propagating to routers without group membership information [RFC3973]. PIM DM attempts to send multicast data to all potential receivers (flooding) and relies upon their self--pruning (removal from the group) to achieve distribution. In PIM DM, multicast traffic is initially flooded to all segments of the network. Routers that have no downstream neighbors or directly connected receivers prune back the unwanted traffic. PIM DM assumes most receivers (hosts, PCs, TV viewers, cellular phone handsets) wish to receive the multicast; therefore the protocol forwards the multicast datagrams everywhere, and then routers prune the distribution tree where it is not needed. PIM is now being utilized for IPTV applications; typically DM is used in the backbone; however, SM could also be utilized in some applications or portions of the overall network.

In SM PIM, only network segments with active receivers that have explicitly requested multicast data are forwarded the traffic. PIM SM relies on an explicit joining request before attempting to send multicast data to receivers of a multicast group. In a PIM SM network, sources must send their traffic to a Rendezvous Point (RP); this traffic is in turn forwarded to receivers on a shared distribution tree. SM works by routers sending PIM Join messages to start the multicast feed being sent across links. The assumption in SM is that relatively few users need the multicast information and therefore PIM SM starts with no flooding of multicast. In short order, router-to-router PIM Join messages cause the multicast stream to be forwarded across links to where it is needed. This is the current standard for Internet Service Providers (ISPs) supporting Internet multicast [WEL200101].

An RP (described in RFC 2362) acts as the meeting place for sources and receivers of multicast data. It is required only in networks running PIM SM and is needed only to start new sessions with sources and receivers. In a PIM SM network, sources send their traffic to the RP; this traffic is in turn forwarded to receivers downstream on a shared distribution

[5] PIM bidirectional (PIM bidir) (a variant of PIM) allows data flow both up and down the same distribution tree. PIM bidir uses only shared tree forwarding, thereby reducing the creation of "state" information.

tree. A Designated Router (DR) is the router on a subnet that is selected to control multicast routes for the members on its directly attached subnet. The receiver sends an IGMP Join message (see below) to this designated multicast router.[6] IP multicast traffic transmitted from the multicast source is distributed over the tree, via the designated router, to the receiver's subnet. When the designated router of the receiver learns about the source, it sends a PIM Join message directly to the source's router, creating a source-based distribution tree, from the source to the receiver. This source tree does not include the RP unless the RP is located within the shortest path between the source and receiver.

Auto-RP is a mechanism where a PIM router learns the set of group-to-RP mappings required for PIM SM. Auto-RP automates the distribution of group-to-RP mappings. To make auto-RP work, a router must be designated as an RP mapping agent that receives the RP announcement messages from the RPs and arbitrates conflicts. Bootstrap Router (BSR) is another mechanism with which a PIM router learns the set of group-to-RP mappings required for PIM SM. BSR operates similarly to Auto-RP: it uses candidate routers for the RP function and for relaying the RP information for a group. RP information is distributed through BSR messages that are carried within PIM messages. PIM messages are link-local multicast messages that travel from PIM router to PIM router. Each method for configuring an RP has its strengths, weaknesses, and complexity. Auto-RP is typically used in a conventional IP multicast network given that it is straightforward to configure, well tested, and stable.

IGMP (Versions 1, 2, and 3) is the protocol used by IP Version 4 (IPv4) hosts to communicate multicast group membership states to multicast routers. IGMP is used to dynamically register individual hosts/receivers on a particular local subnet (e.g., LAN) to a multicast group. IGMPv1 defined the basic mechanism. It supports a Membership Query (MQ) message and a Membership Report (MR) message. Most implementations at press time employed IGMPv2; Version 2 adds Leave Group (LG) messages. Version 3 adds source awareness allowing the inclusion or exclusion of sources. IGMP allows group membership lists to be dynamically maintained. The host (user) sends an IGMP "report," or join, to the router to be included in the group. Periodically, the router sends a "query" to learn which hosts (users) are still part of a group. If a host wishes to continue its group membership, it responds to the query with a "report." If the host does not send a "report," the router prunes the group list to delete this host; this eliminates unnecessary network transmissions. With IGMPv2, a host may send a "leave group" message to alert the router that it is no longer participating in a multicast group; this allows the router to prune the group list to delete this host before the next query is scheduled, thereby minimizing the time period during which unneeded transmissions are forwarded to the network.

[6] This is different from the router-to-router PIM Join message just described; this message is from a receiver to its gateway multicast router.

Other basic multicast protocols/mechanisms include the following:

- IGMP snooping is a method by which a switch can constrain multicast packets to only those ports that have requested the stream IGMP.
- MLDv2 is a protocol that allows a host to inform its neighboring routers of its desire to receive IPv6 multicast transmissions; it is similar to (and based on) IGMPv3 used in the IPv4 context.
- STUB multicast routing is a mechanism that allows IGMP messages to be forwarded through a non-PIM-enabled router toward a PIM-enabled router.
- PIM SSM is a multicast protocol where forwarding uses only source-based forwarding trees. IGMPv3 is used to support SSM. SSM mapping is a mapping that allows SSM routing to occur without IGMPv3 being present. SSM mapping uses statically configured tables or dynamic Domain Name System (DNS) discovery of the source address for a SSM channel.
- MSDP is a protocol that allows multiple PIM SM domains to share information about active sources. The protocol announces active sources to MSDP peers.
- MPBGP is a protocol that defines multiprotocol extensions to the BGP, the unicast interdomain protocol that supports multicast-specific routing information. MPBGP augments BGP to enable multicast routing policy and connect multicast topologies within and between BGP autonomous systems. It carries multiple instances of routes for unicast routing as well as multicast routing.
- Pragmatic General Multicast (PGM) is a reliable multicast transport protocol for applications that require ordered, duplicate-free multicast data delivery. The protocol guarantees that a receiver in a multicast group receives all data packets from direct transmissions or via retransmissions of lost packets. PGM can detect unrecoverable data packet loss.
- RGMP is a protocol that constrains IP multicast on switches that have only routers attached.

Some of these protocols (but not all) are covered in the chapters.

Figure 1.2 illustrates where some of these protocols apply in the context of a typical multicast network.

It should be noted that the design and turnup of IP multicast networks is fairly complex. This is because by its very nature IP multicast traffic is "blasted all over the map"; hence, a simple design mistake (or oversight) will push traffic to many interfaces and easily flood and swamp router and switch interfaces.[7]

[7] This statement is based on some 100-h weeks spent by the author configuring IPTV networks while endeavoring to meet established business deadlines.

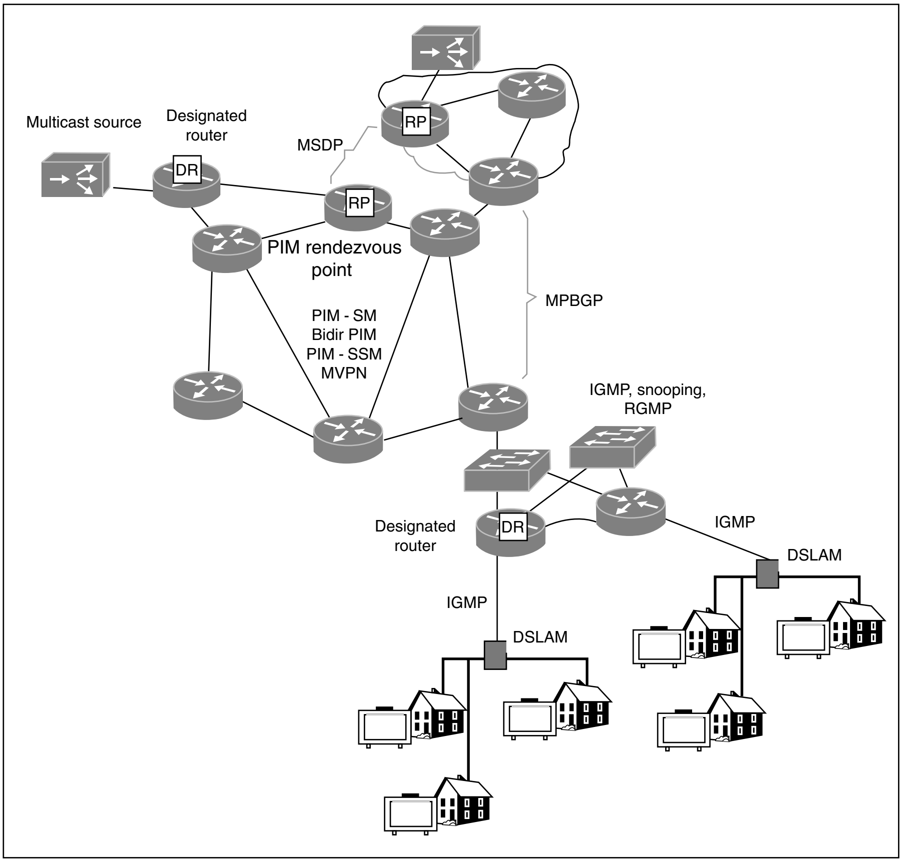

Figure 1.2. Multicast Protocols Usage in a Typical Multicast Network

1.4 IPTV AND DVB-H APPLICATIONS

While IP multicast has been around for a number of years, it is now finding fertile commercial applications in the IPTV and DVB-H arenas. Applications such as datacasting (e.g., stock market or other financial data) tend to make use of large multihop networks; pruning is often employed and nodal store-and-forward approaches are totally acceptable. Applications such as video are very sensitive to end-to-end delay, jitter, and (uncorrectable) packet loss; QoS considerations are critical. These networks tend to have fewer hops, and pruning may be somewhat trivially implemented by making use of a simplified network topology.

IPTV services enable advanced content viewing and navigation by consumers; the technology is rapidly emerging and becoming commercially available. IPTV services enable traditional carriers to deliver SD and HD video to their customers in support of their triple/quadruple play strategies. With the significant erosion in revenues from traditional voice services on wireline-originated calls (both in terms of depressed pricing and a shift to voice over IP (VoIP) over broadband Internet services delivered over cable TV infrastructure) and with the transition of many customers from wireline to wireless services, the traditional telephone carriers find themselves in need of generating new revenues by seeking to deliver video services to their customers. Traditional phone carriers find themselves challenged in the voice arena (by VoIP and other providers); their Internet services are also challenged in the broadband Internet access arena (by cable TV companies); and their video services are nascent and challenged by a lack of deployed technology. Multimedia (and new media) services are a way to improve telco revenues (e.g., but not limited to, [MIN198601], [MIN199301], [MIN199401], [MIN199402], [MIN199403], [MIN199404], [MIN199501], [MIN199502], [MIN199503], [MIN199504], [MIN199505], [MIN199601], [MIN199602], [MIN199603], [MIN199701], [MIN199702], [MIN199801], [MIN199802], [MIN199803], [MIN199804], [MIN200001], [MIN200301]).

There was a recognition in the mid-1990s that a video strategy was important, and considerable technical work was undertaken under the Federal Communications Commission (FCC's) Video Dialtone Initiative. That effort was described by this author in the well-received book *Video Dialtone Technology: Digital Video over ADSL, HFC, FTTC, and ATM*, McGraw-Hill, 1995 [MIN199501]. In 1992, various telcos filed applications with the FCC for a service called "video dialtone" that would have allowed phone companies to use their networks to compete with cable television distributors. By 1995, according to FCC reports, 24 applications were completed representing 43 different cities/states to be upgraded. As far back as 1997, 9.7 million homes should have received this service. These upgrades were supposed to handle 500+ channels on average. Table 1.2 is a compilation of telco commitments filed with the FCC [KUS200601]. Unfortunately, none of these plans led to actual TV services.

The problem was that the emphasis by the telcos for local delivery was totally pivoted on Digital Subscriber Line (DSL). DSL had a bandwidth range of around 1.5 Mbps when using mid-1990s technology. Consequently, the use of MPEG-1 encoding techniques operating at 1.5 Mbps limited the domicile access to a single stream of video into a home at any point in time, which was a market nonstarter [MIN200001]. In addition, the Asynchronous Transfer Mode (ATM) core infrastructure turned out to be expensive. Now a decade later, in the mid-to-late 2000s, the recognition has emerged that an IP infrastructure (with IP multicast) is the best mechanism for distribution of entertainment video by the telcos, aiming at a 200–300-channel pool and typically with up to three simultaneous streams of video traffic per domicile based on efficient, yet high-quality, MPEG-4 standards (e.g., see [MIN200301]). The current delivery model is state-of-the-art DSL services and possibly Very High Data Rate DSL (VDSL)/VDSL2 (see Table 1.3, [DSL200701]) in the near term and Fiber To The Home (FTTH) in the longer term. Tier 2 and tier 3 telcos may rely on VDSL/VDSL2 for the next few years, while at least some tier 1 telcos (e.g., Verizon FiOS) may move to in short order, or already use, FTTH technologies. Figures 1.3 and 1.4 illustrate a simplified IPTV application from an infrastructure perspective.

Some of the areas that require consideration and technical support to develop and deploy IPTV systems include the following, among many others: